MATHEMATIC MODEL AND CONTROL METHOD BASED ON HYBRID INTELLIGENCE

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Abstract

A mathematic model based on RBF(Radial Basic Function) neural network and genetic algorithm for multivariable optimal control with the lowest operational cost by limiting total substrate discharge in activated sludge process were discussed. It shows that the RBF neural network has preferable convergence for modeling the process. On the whole, mapping is nonlinear from inputs to output of RBF network; and output of network is linear to adjustable parameter. The RBF neural network was trained and simulated by a lot of observed data, and the result showed that the RBF neural network may be used to model the process and predict the water quality of outlet of SBR(Sequential Batch Reactive Mud Method) system. Genetic algorithm is an effective searching method to resolve the optimal problem in this case. Based on satisfying the requirements of precision, binary coding is used to express units, and 20 bits of binary digits express DO(Deliquescent Oxygen), Q_w separately. According to the adaptive degree of units, which can be operated genetically through genetic operator, superior units can be saved, inferior ones are eliminated, and a group of new units can be obtained. This algorithm avoids the difficulty of guessing iteration initial value and increases calculation efficiency, The optimization strategy made up of RBF neural network and genetic algorithms is adopted. After achieving the discharge standard of biochemical oxygen demand, the control rule for variables to make operation cost be least is found by simulation.

Keywords: Mathematic model, RBF neural network, Genetic algorithm, Sewage disposal process, Simulation.

Presenting Author's biography

Zaiwen Liu. male, was born in Beijing, China. Now he is a professor in the School of Information Engineering, Beijing Technology and Business University. His research mainly includes system modeling and simulation, intelligence control, computer control system and measurement control network.

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1 Introduction

Optimal control, which is the highest control mode in control process, is applied widely in some of industrial process. Information acquisition and processing is very important for modeling and optimizing a control system. By solving the state equation and objective function (performance index or index function) under constraint conditions, the system can be operated, and performance indexes can be optimized furthest.

Suppose that control variables aren't restricted or permissible control is available, it can be discussed through classical calculus of variation theory. However, control has been restricted in many practical problems. Now, one good solution about restricted optimal control is to transform it into an unrestricted problem by penalty function. There are many traditional algorithms to unrestricted optimal, such as gradient method (fastest descent method), Newton method and its various deformation, conjugate gradient method, changing dimension method (including DFP method, Pearson method), Powell method etc., but only local solution can be obtained through these algorithms. Furthermore, restricted optimal control problem is to be resolved by means of penalty function method, which asks penalty factor to be infinite. If some traditional algorithms are adopted at that time, pathological form problem is easy to happen. This restricts the application of traditional algorithms further[1-2].

Because of the problems mentioned above, genetic algorithm is brought in the optimal control of process control, such as sewage treatment process. Genetic algorithm, based on natural selection and group heredity mechanism, is an effective searching method to resolve optimal problem. It is an algorithm looking for superior solution in overall situation.

Comparing with traditional optimal algorithms, genetic algorithm is of these characteristics: strong robust, parallel processing, wide application etc., furthermore, genetic algorithm can be applied to some complicated nonlinear problems especially. It is only function values, not differential coefficient that needs to be obtained in Genetic algorithm, consequently, in the resolution of restricted optimal control problem with penalty function method, pathological form problem are not caused even the value of penalty factor is very big. That decreases the calculation greatly[3].

As the water quality and water quantity of inflow change every moment, the treatment process of domestic sewage and industrial effluent are operated in a state of instability. This is to cause the ceaseless changes of other parameters and outflow quality. In recent years, automatic control of sewage disposal plant has been spread and extended increasingly, however, its optimal control has not been realized till today.

2 Model Based on neural network

2.1 RBF (radial basis function) neural network

RBF neural network can approach any nonlinear functions in given precision, and there is inexistence of local extremum. On the whole, mapping is nonlinear from input of network to output of network; at the same time output of network is linear to adjustable parameter.

The output of RBF nerve cell is showed as:

$$a = radbas(\|w - p\| b) \tag{1}$$

Where b is threshold of hidden layer, w is weighting value, and p is output value. $\|w - p\|$ express distance between input vector and output vector.

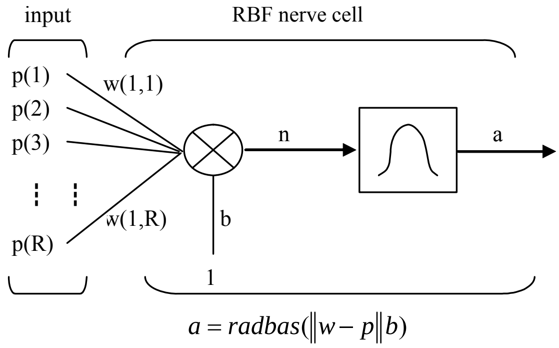

Fig.1 RBF nerve cell

The outputs of export layer means the sum of output adding values of hidden layers, it can express as:

$$Y_k = \sum_{i=1}^{m} W_{ik} R_i(X) \tag{2}$$

$k = 1, 2, \cdots, q$

q is the number of output nodes.

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2.2 Modeling of activated sludge process

According to analysis of activated sludge process, the reaction time t ,DO,S and X are selected as inputs, S' 、X' , Z, Q_w and Jc are the outputs of the network.

S is BOD concentration, X is MLSS concentration, Z is organic discharge gross, Q_w is sludge discharge, and Jc means operation cost.

S' 、X' express BOD concentration and MLSS concentration respectively, which have run a period of time in aeration basin.

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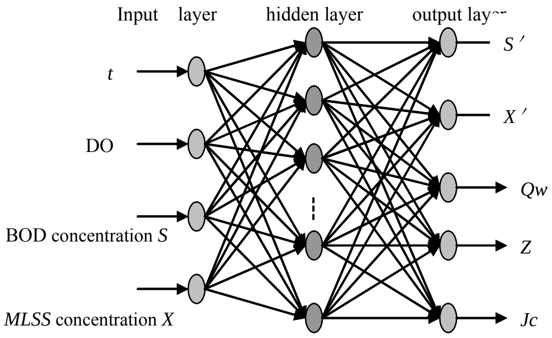


Fig.2 Configulation of RBF neural network

2.3 Learning algorithm of RBF neural network

The center of RBF is confirmed by the supervise method, error correct method is based gradient descent, and objective function show as:

$$E = \frac{1}{2}\sum_{j=1}^{N} e_j^{\,2} \tag{3}$$

$$e_j = d_j - F^*(x_j) = d_j - \sum_{i=1}^{m} w_i G(\|x_j - t_i\|_{ci}) \tag{4}$$

Where N is the number of output nodes. m is the number of selected hidden layers, w_{ji} , t_i 和 σ_i^{-1} are the parameters to be learning.

The following steps are the learning rules of error correct method based on gradient descent.

1) Weighting value of output

$$\frac{\partial E(n)}{\partial w_i(n)} = \sum_{j=1}^{N} e_j(n) G(\|x_j - t_i(n)\|_{ci}) \tag{5}$$

$$w_i(n+1) = w_i(n) - \eta_i \frac{\partial E(n)}{\partial w_i(n)} \tag{6}$$

i =1,2,⋯,m.

2) The center of hidden nodes

$$\frac{\partial E(n)}{\partial t_i(n)} = 2w_i(n)\sum_{j=1}^{N} e_j(n) G'(\|x_j - t_i(n)\|_{ci}) \textstyle\sum_i^{-1}(n)[x_j - t_i(n)] \tag{7}$$

$$t_i(n+1) = t_i(n) - \eta_2 \frac{\partial E(n)}{\partial t_i(n)} \tag{8}$$

i =1,2,⋯,m.

3) Width of RBF

$$\frac{\partial E(n)}{\partial \sum_i^{-1}(n)} = -w_i(n)\sum_{j=1}^{N} e_j(n) G'(\|x_j - t_i(n)\|_{ci})[x_j - t_i(n)]^T \tag{9}$$

$$\textstyle\sum_i^{-1}(n+1) = \sum_i^{-1}(n) - \eta_3 \frac{\partial E(n)}{\partial \sum_i^{-1}(n)} \tag{10}$$

i=1,2,…,m .

$G'(\cdot)$ is the derivative of green function, and η_1, η_2, η_3 is the learning speed.

2.4 Capability of neural network

The RBF neural network is trained by experimental data of 25 groups. Basis function of hidden node of RBF network has a local reaction to input signal by nonlinear changing, and the common basis function is gauss function. The error curve of training is showed as Fig.3. It seems that the RBF neural network has preferable convergence for modeling the wastewater treatment process.

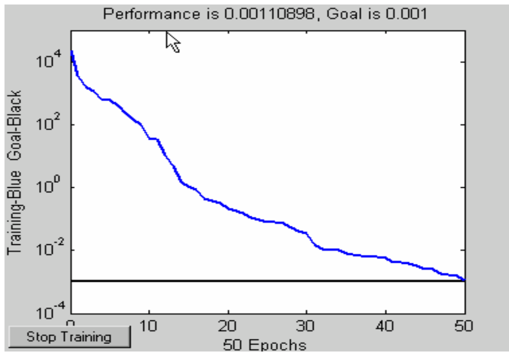


Fig.3 Error curve of the neural network training

3 Performance of optimal control

3.1 The objective of optimal control

At present, there are two problems existing commonly in sewage treatment plant: the density or the fluctuation of substrate (organic material) from outflow is high and the operation fee is expensive.

This paper researches on optimal control by connecting these two problems, considering sewage discharge amount (Q_w) and dissolved oxygen (DO) concentration in aeration basin as control variables, the sum of operation cost (energy consumption) including surplus sludge treatment, inverse sludge and aeration basin as performance indexes, water quality of outflow as the constraint. Obviously, Q_w and DO are the most important input parameters in the operation of activated sludge process except water quality and water quantity of inflow. Most of the operation cost in activated sludge process is involved in the performance indexes of this research. Based on meeting the requirement of outflow water quality, the most important aim is to decrease the operation cost.

3.2 Performance indexes

Obviously, the operation cost of sewage treatment system is relative to control variables DO and Q_w. Let everyday operation cost be Jc, which consists of disposal cost of surplus sewage J_1, inverse sewage cost J_2, oxygen supply cost J_3.

$$J_C = J_1 + J_2 + J_3 \quad (11)$$

In nonstable state, the operation cost of activated sludge process for one day can be expressed as by function [4-5].

$$J_C = \int_0^1 \left\{ AQ_w X + \frac{BX(Q - Q_w)}{X_r - X} + \frac{C_1(D_s - DO_1)}{D_s - DO} \left[\frac{VXDO}{K_o + DO} \left(\frac{akS}{K_s + S} + 1.42K_d \right) + Q \cdot DO \right] \right\} dt \quad (12)$$

Where Q, Qr, Q --- flow quantity of inflow, inverse sludge and sludge discharge (m3/d)

X, Xr --- MLSS and inverse sludge density (mg/L).

So, S --- substrate density (BOD) of inflow and outflow (aeration basin).

DO--- dissolved oxygen density (mg/L).

V--- available capacity of aeration basin (m3).

R--- inverse sludge ratio.

In order to fit for the restricted conditions of organic discharge gross, one state variable $Z(t)$ is added to state equation. $Z(t)$ represents that organic discharge gross of outflow everyday changes following time t.

$$Z(t) = \int_0^t QSdt \quad (13)$$

Because the initial value of $Z(0)=0$, the end value $Z(1)$ represents organic discharge gross in every day

$$Z(1) = \int_0^1 QSdt \quad (14)$$

The restricted condition can be expressed as:

$$Z_S - Z(1) \geq 0$$

$$0 < DO \leq D_S$$

$$Q_W > 0 \quad (15)$$

Zs --- organic discharge gross allowed in every day.

Let Zs=150kg(BOD)/d, which represents that average outflow BOD is 15mg/L.

4 Genetic algorithms of optimal control

4.1 Characters of genetic algorithms

Genetic algorithm, based on natural selection and group heredity mechanism, is an effective searching method to resolve optimal problem. It imitates the population, crossover and mutation in natural selection process and natural heredity process. Every possible solution is considered as every unit (chromosome) of colony, furthermore, every unit is coded in the form of character string. After that, every unit is evaluated in terms of expected objective function and an adaptive degree is put forward. Some units are always produced randomly when genetic algorithm iterates.

According to the adaptive degree of units, which can be operated genetically through genetic operator, superior units can be saved, inferior ones are eliminated, a group of new units can be obtained. Because inheriting excellent character from the former generation, these new units are superior to the former ones and the algorithm develops toward the direction of better solutions. Genetic algorithms need not complicated calculations to resolve complex optimal problems. The optimal solutions can be obtained only by several kinds of operators (selection, crossover, mutation etc.). It is an algorithm looking for superior solution in overall situations[6-7].

4.2 Design of genetic algorithm

1) Coding of parameters

Because binary coding has many the advantages, such as easy operation for coding and decoding ,and easy realization for crossover, mutation etc. This paper applies binary coding to express units. Based on satisfying the requirements of precision, 20 bits of binary digits are employed to express DO, Q_w separately.

2) Enactment of initial colony

Initial solution colony is made of N feasible solutions by random method.

3) Calculation of fitness function

In order to obtain fitness function of every unit, he solution is brought in fitness function. The restricted conditions of end value (organic discharge gross in every day) are calculated in penalty strategy. In order to transform the restricted problems into unrestricted ones, some penalty items should be added in fitness function to punish the unfeasible solutions.

$$V(DO, Q_w)=F(DO, Q_w)+G\times P(DO, Q_w) \quad (16)$$

G --- penalty coefficient

4) Selection

Sort algorithm of standard geometry is adopted in selective function. Selective probability Pi is defined for every unit:

$$p_i = \frac{q(1-q)^{n-i}}{1-(1-q)^n} \quad (17)$$

Pi --- The selective probability of unit i

n --- The number of unit in colony

q --- Optimal probability of selection

The selective probability of a chromosome only lies on its sequence by big and small in the colony. The offspring number of his chromosome is not affected by the situation that adaptive value of chromosome is bigger or smaller than that of others, so that over-centralized state of chromosomes is avoided after selection to a certain extent.

5) Crossover

One-point crossover technology is used in it. Based on crossover probability Pc, one crossover point is chosen randomly for every couple of selected units. Two new units (child 1, child 2) are born after the part exchange between the couple selected.

child1=parent11～curr_site+parent2curr_site+1～sz

child2=parent21 ～ curr_site+parent1curr_site+1 ～ sz (18)

curr_site --- crossover position

6) Mutation

Parameter Pm is defined as aberrant probability which represents that units of expectation value P m·n are selected for aberrant operation in this colony. Every parent generation selected is operated aberrantly (reverse every bit of the unit) and one generation is obtained:

child ： child=parent1 ～ mutate_site-1+/parentmutate_site+parentmutate_site+1～sz (19)

mutate_site --- aberrant position

7) Repeat steps 3)-6)until the optimal solution is obtained to satisfy precision requirement or largest aberrant algebra.

5 Simulation and application

Give an example for the simulation: the optimal control of sewage treatment process with an aeration basin whose available capacity is 2500m3.

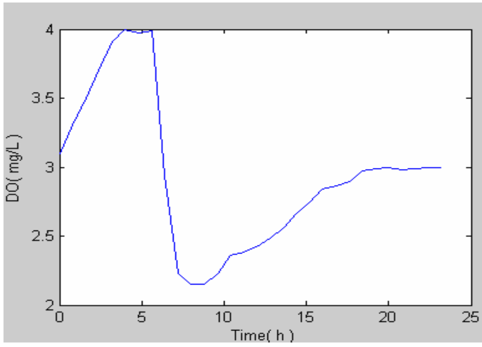
Let water quantity of inflow Q and density of inflow substrate (BOD) change as sine wave following time everyday:

$$Q = Q(t) = \overline{Q} + 5000\sin(2\pi t)$$
$$S_o = S_o(t) = \overline{S}_o + 0.05\sin(2\pi t) \quad (20)$$

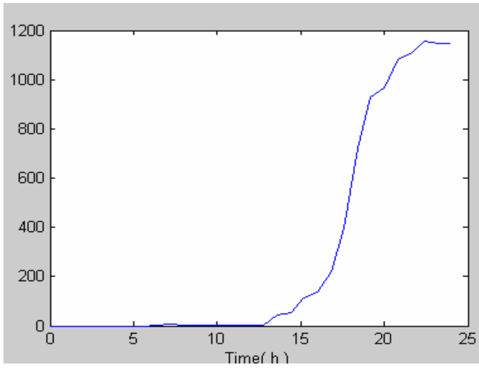
Where $\overline{Q}$ --- Average value of inflow quantity, let $\overline{Q}$ =10000 m3/d.

$\overline{S}_0$ --- Average value of substrate density of inflow, let $\overline{S}_0$ =0.150 kg/m3.

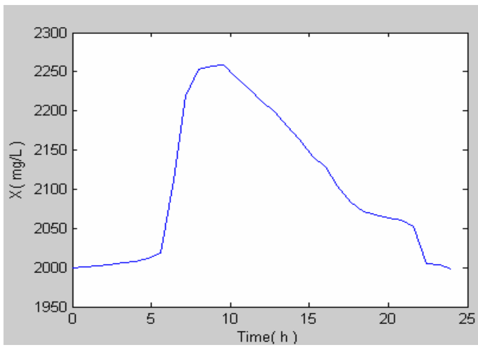
Let colony size N=100, aberrant probability be 0.05, crossover probability be 0.8, largest aberrant algebra be 40, X_0=2000.0mg/L，S_0=9.96 mg/L. The result of simulation is shown in Fig.2 in which Fig.4 (a), (b) are optimal curves of dissolved oxygen density DO and sludge discharge flow Q_w separately, and Fig.4 (c), (d) are changing curves of MLSS density and substrate density X of aeration basin S following optimal control.



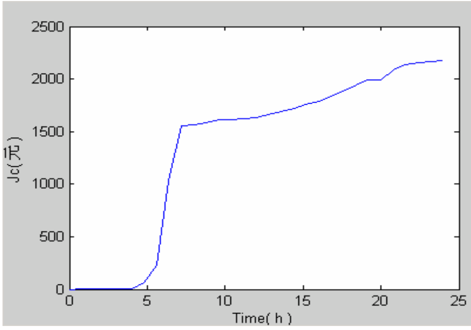
(a) Curve of DO density



（b）Sludge discharge flow Qw(m3/d)



(c) Curve of MLSS density X



(d) Curve of *Jc* (yuan)

Fig.4 Curves of simulation results

Consequently, DO can be controlled between 0.5~6.08 mg/L, so that the substrate discharged everyday can be controlled below 150kg (BOD)/d and the lowest operation cost of sewage treatment can be realized.

6 Conclusions

The mathematical model establishment of activated sludge method is basic content of optimization study in the process of sewage disposal. It shows that the RBF neural network has preferable convergence for modeling the wastewater treatment process,. A mathematical model based on RBF neural network can reflect the change process, the disposal effect and cost in sewage disposal. The neural network model can get rid of the restriction that mechanism modeling needs much supposed condition, and it can reflect the internal rules. The modeling to activated sludge method based on neural network is a newer method.

Genetic algorithm is an effective searching method to resolve the optimal problem in this case. According to the adaptive degree of units, superior units can be saved, inferior ones are eliminated, and a group of new units can be obtained. Then the optimal control can be imitated by automatic control based on the changing principles of optimal control variable DO and Q_w in the wastewater treatment system.

The genetic algorithms in this paper is adopted to optimize and study the process of sewage disposal. The control parameter (DO) is coded in binary system and the initial colony was created at random. The fitness function is *Jc*. The stop condition is the biggest evolution algebra. Selection operation adopts proportional model. Crossover operation adopts single dot crossover. To find out a group of DO and Q_w, which satisfied the restrained factors (Z) and made the operation cost be least. The choice of fitness function exhibits optimization strategy based on neural network and genetic algorithms.

The genetic algorithm is a kind of pseudo-zoology random optimization arithmetic. Compared to traditional optimization methods, its implement process is simpler, and can get global optimal result. Nowadays it is infrequent to optimize and study the process of sewage disposal with generic algorithms.

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